Medical management of patients after atypical femur fractures

Medical management of patients after atypical femur fractures: a systematic review and recommendations from ECTS*

* *European Calcified Tissue Society*

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Additional data have been included with this submission in Supplement 1 (1).

Abstract

Context. Atypical femur fractures (AFFs) are serious adverse events associated with bisphosphonates and often show poor healing.

Evidence acquisition. We performed a systematic review to evaluate effects of teriparatide, raloxifene and denosumab on healing and occurrence of AFF.

Evidence synthesis. We retrieved 910 references and reviewed 67 papers, including 31 case reports, nine retrospective and three prospective studies on teriparatide. There were no randomized controlled trials. We pooled data on fracture union (n=98 AFFs on teriparatide) and found that radiological healing occurred within six months of teriparatide in 13 of 30 conservatively managed incomplete AFFs (43%), nine of 10 incomplete AFFs with surgical intervention (90%) and 44 of 58 complete AFFs (75%). In nine of 30 non-operated incomplete AFFs (30%) no union was achieved after 12 months and four fractures (13%) became complete on teriparatide. Eight patients had new AFFs during or after teriparatide. AFF on denosumab was reported in 22 patients, including 11 patients treated for bone metastases and eight without bisphosphonate exposure. Denosumab after AFF was associated with recurrent incomplete AFFs in one patient and two cases of contralateral complete AFF. Eight patients had used raloxifene before AFF occurred, including one bisphosphonate-naïve patient.

Conclusions. There is no evidence-based indication in patients with AFF for teriparatide apart from reducing the risk of typical fragility fractures, although observational data suggest that teriparatide might result in faster healing of surgically treated AFFs. Awaiting further evidence, we formulate recommendations for treatment after an AFF based on expert opinion.

Introduction

Antiresorptive drugs such as bisphosphonates are widely used for the treatment of osteoporosis. Although effective for prevention of osteoporotic fractures, use of bisphosphonates is associated with rare but serious adverse events such as osteonecrosis of the jaw and atypical femur fractures (AFFs). An AFF is a spontaneous or low-trauma, subtrochanteric or femur shaft fracture often complicated by delayed or non-union (26%-39%) and bilateral occurrence (2, 3).

The age-adjusted incidence rate of AFF has been estimated to be 1.8 per 100,0000 person-years in patients on bisphosphonate use under two years, increasing to 113 per 100,000 person-years with over 8 years' duration (4). It is thought that decreased bone resorption in bisphosphonate users results in suppressed bone turnover with accumulation of microcracks and homogeneously mineralized bone, making the bone more brittle and allowing the development of a spontaneous femur fracture. However, it is uncertain if bisphosphonates are causally related to AFF and incidentally AFFs do occur in bisphosphonate-naïve individuals (5). Usually, bisphosphonates are discontinued after AFF is diagnosed. It has been shown that the risk of AFF decreases with 70% per year since the last use of antiresorptive drugs (6), although it is not certain that this risk reduction is also seen in patients who have already sustained an AFF.

It is unclear if alternative osteoporosis drugs, particularly anabolic drugs, can promote AFF healing. Moreover, there is no guideline on how patients should be treated after an AFF where the risk of causing new atypical fractures should be weighed against the risk of fragility fractures when not treating osteoporosis. It has been proposed that teriparatide, an analog of parathyroid hormone (PTH 1-34) , is a safe option for treatment of osteoporosis in AFF patients, especially since it may also have a beneficial effect on the healing of AFF itself (7). Teriparatide is the only anabolic osteoporosis drug that is currently globally available. It

directly stimulates osteoblasts that might enable the formation of new, heterogeneously mineralized, bone at the fracture site of AFF. Besides teriparatide, antiresorptive drugs other than bisphosphonates, such as raloxifene and denosumab, may be considered for osteoporosis treatment in AFF patients. Denosumab is a human monoclonal antibody to RANKL and a potent inhibitor of bone resorption. Although AFFs have been reported in patients exposed to denosumab in case reports, it has not been clearly established in epidemiological studies how often denosumab, with or without preceding bisphosphonate use, is associated with AFF. The radiological healing or deterioration of AFF whilst on denosumab treatment is also not known. Raloxifene is a selective estrogen receptor modulator (SERM) that acts as an estrogen agonist in bone, with an antiresorptive effect that is milder than that of bisphosphonates and denosumab. The relationship between raloxifene and the occurrence of AFF has not been investigated. To our knowledge, this is the first review that explored denosumab and raloxifene in addition to teriparatide for medical management of osteoporosis in patients with AFF. Further, we investigated whether AFF occurs as an adverse event in clinical trials with two novel drugs for osteoporosis, romosozumab and abaloparatide. Romosozumab, an antibody to sclerostin with both anabolic and antiresorptive effects, was recently approved in Europe, Japan and the U.S. for the treatment of (severe) osteoporosis. Abaloparatide is a synthetic analog of parathyroid hormone related protein. Strontium ranelate was not included in this review, since this drug is no longer available in most countries.

We performed a systematic literature review to assess both the occurrence and the radiological healing of AFFs in patients who had used or were using teriparatide, denosumab or raloxifene. We formulate recommendations for healing of the AFF itself and for osteoporosis management in patients who have sustained an AFF and are at high risk of fragility fractures.

Methods

We performed a search using key words related to atypical femur fractures and teriparatide, denosumab and/or raloxifene in Embase, Medline Epub (Ovid), Web of Science and Cochrane Central on 28th of May 2018. We separately searched for AFF as an adverse event in clinical trials with romosozumab or abaloparatide. Reviews and articles written in a language other than English were excluded. Conference abstracts and original research articles were included. Articles were reviewed when AFF was diagnosed during or after the use of teriparatide, denosumab and raloxifene or when the radiological healing of AFF in a specified amount of time was reported using these drugs.

A complete AFF was defined as a non-comminuted subtrochanteric or femur shaft fracture with a predominantly transverse fracture line that may become oblique as it progresses medially, after no or minimal trauma. An incomplete form of AFF was defined as a localized endosteal or periosteal thickening of the lateral cortex of the subtrochanteric femur with or without the presence of a lucent line. When the authors did not describe whether a fracture line was visible, we assessed medical imaging in the article to review the presence of a fracture line.

We extracted data on sex, median age, ethnicity, use of bisphosphonates, surgical interventions and clinical or functional outcome after the AFF as far as this information was available.

We assessed the occurrence of newly diagnosed AFF during or after the use of teriparatide, denosumab or raloxifene. Newly diagnosed AFF could either be the first clinical presentation of AFF, a second AFF of the contralateral femur, or recurrent AFF at the ipsilateral femur. For the assessment of radiological healing, the results were categorized for each type of drug according to study design (case report, retrospective cohort and prospective studies) and fracture type (complete AFF, incomplete AFF with or without surgical treatment) (**Figure 1**).

We assessed the total number of AFFs described in the literature with complete radiological healing at six months and 12 months after medical management. The number of conservatively treated incomplete AFFs that developed a lucent line or progressed to complete AFF was also noted. We pooled these data on healing from all article types to provide better insight into the effectiveness of the drugs for the healing of AFF. Radiological healing in complete AFFs and surgically treated incomplete AFFs was defined as adequate callus bridging. Radiological healing of an incomplete AFF on conservative management was defined by disappearance of a visible fracture line. Radiological healing of incomplete AFFs without a lucent line included flattening of cortical thickening, disappearance of bone marrow edema on MRI-scan, or fading of hotspots on bone scintigraphy. Incomplete AFFs with localized cortical thickening only, without abnormalities on MRI-scan or bone scintigraphy were excluded from assessment of radiological healing, because focal cortical thickening can remain unchanged for more than five years after diagnosis of incomplete AFF (8).

We give our recommendations for teriparatide, denosumab and raloxifene in the medical treatment of patients with AFF. In order to address the decision-making in individual cases, we have formulated treatment advice for patients with a new diagnosis of AFF and patients with AFF who have completed a two-year course of teriparatide. These considerations are based on the findings in this review and our expert opinion.

Results: systematic review

Our search retrieved 910 references. We selected two conference abstracts and 130 articles after screening of title and abstract. We replaced one conference abstract with the article that was published shortly after our search date (9, 10). After full-text reading, 67 articles were included for this review. Sections on teriparatide, denosumab and raloxifene have overlapping

references, because some case descriptions report on a combination of these treatments in AFF patients.

Teriparatide

We found 31 case reports, nine retrospective cohort studies and three prospective studies that have reported the effect of teriparatide on the radiological healing of AFF or occurrence of AFF. There were no published randomized controlled trials (RCTs). Detailed study descriptions of case reports, retrospective cohorts and prospective studies on teriparatide use in AFF patients can be found in **Supplement 1**(1). The demographic characteristics of the patients with AFF on teriparatide in case reports are stated in **Table 1.** Clinical variables and main findings from retrospective cohorts and prospective studies are summarized in **Table 2** and **Table 3**, respectively. The pooled data on radiological healing of AFF with teriparatide treatment are shown in **Table 4**.

Teriparatide use and occurrence of AFF

New AFF cases during or after teriparatide use were reported in eight patients and always occurred in patients with previous bisphosphonate exposure. The new AFFs occurred after 4, 11, 18 and 24 months of teriparatide treatment in four patients (11-14). The remaining four patients were described in a conference abstract which did not report the duration of teriparatide at time of diagnosis, but all developed new incomplete AFFs during teriparatide therapy in the same femur in which the first incomplete AFF was diagnosed (15).

Six of the eight patients had been diagnosed with another AFF before, but in two patients the AFFs during teriparatide were the first AFFs (12, 13). One patient was diagnosed with a complete and contralateral incomplete AFF two years after stopping teriparatide without any

antiresorptive use in the meantime, but the patient had been treated for eight years with antiresorptives in the past (12).

Teriparatide use after AFF

Descriptive data of case reports, retrospective and prospective studies

In 33 patients, a total of 24 incomplete AFFs and 27 complete AFFs were reported at the time of starting teriparatide treatment in 31 case reports. In 13 incomplete AFFs (54%) a fracture line was described or visible on the images in the publication, whilst the other cases of incomplete AFFs only showed focal cortical thickening on X-ray. The majority of cases were women (n=27, 82%). The mean age of all AFF patients was 67 years, ranging from 21 to 84 years. Only a minority of studies (39%) reported ethnicity in 13 patients of whom nine were Caucasian. All cases of AFF were associated with the use of bisphosphonates. A total of 27 patients (82%) were previously exposed to alendronate therapy. The mean treatment duration with antiresorptive drugs was 8.3 years, with a minimum duration of two years and a maximum exposure of 17 years. Three patients were diagnosed before the AFF with osteogenesis imperfecta (16-18) and one patient was genetically tested after the occurrence of bilateral incomplete AFFs which revealed hypophosphatasia (19).

Nine retrospective cohorts that comprised a total of 201 AFF patients reported the effect of teriparatide use on radiological healing. Five cohorts involved incomplete forms only (15, 20-23), three cohorts described complete fractures only (24-26) and one cohort was mixed (27). Six cohorts consisted of entirely Asian populations. In eight cohorts, all AFF cases were exposed to antiresorptive therapy and one cohort had 23% bisphosphonate-naïve patients. Three prospective studies comprised a total of 31 women and one man with a mean age of 73 years who were treated for bisphosphonate-associated AFFs with teriparatide. Only one of

these studies had controls (n=9 patients) without teriparatide treatment (28). All three studies had a mix of complete and incomplete AFFs. Teriparatide was started immediately after surgery in one study and compared to delayed commencement of teriparatide six months postoperatively (29), whilst in the other two studies teriparatide was started between seven weeks to just over one year after the diagnosis of AFF (28, 30). The study by Greenspan et al. included four individuals with periprosthetic fractures (29), which strictly does not adhere to the diagnostic criteria for AFF as formulated by the American Society for Bone and Mineral Research (ASBMR) (3).

Radiological healing of AFF after teriparatide: pooled data

We pooled findings on fracture union and teriparatide use in case reports and retrospective studies. Apart from deterioration of incomplete AFFs to complete fractures in two patients (30), no data on radiological healing from the three prospective studies could be used for this analysis, because either the fracture type (28) or time to healing (29, 30) could not be established from these publications.

Data on fracture healing of 165 AFFs in 140 patients were pooled in **Table 4**, of which 96% were women (11, 14, 16-18, 21-27, 30-49). Teriparatide treatment was given for 98 AFFs (59%) while 67 AFFs from control groups in the cohort studies (all complete AFFs) did not receive teriparatide. The number of incomplete non-operated AFFs without teriparatide was too small for comparison (n=4) and there were no controls for surgically managed incomplete AFF. Healing of the fracture was achieved within six months of starting teriparatide in 13 (43%) incomplete non-operated AFFs, nine (90%) surgically treated incomplete AFFs and 44 (76%) complete AFFs. In the non-teriparatide treated group, 34 complete AFFs (51%) healed within six months. Complete AFFs appeared to heal faster with teriparatide compared to controls without teriparatide, but in both groups non-healing occurred at 12 months postoperatively in a small portion of patients: five AFFs (9%) in the teriparatide users; and four AFFs (6%) in those without teriparatide. Teriparatide was started in 11 patients because of signs of delayed healing or nonunion, ranging from two months to two years after the initial diagnosis of AFF (n=2 incomplete conservatively managed AFFs, n=9 complete AFFs) (14, 17, 18, 26, 31, 34, 36, 39, 41, 42, 44). Sixteen patients with 18 fractures had not discontinued bisphosphonates immediately after the diagnosis of AFF, ranging from three weeks up to one year, including four AFFs in four patients in the teriparatide-treated group (n=2 incomplete conservatively managed AFFs, n=2 complete AFFs) and 12 controls with 14 complete AFFs (24, 25, 30, 31, 45). Progression from incomplete to complete AFFs occurred

in four patients after initiation of teriparatide at varying intervals: nine days, two months, eight months, and 21 months (23, 30, 48).

Denosumab

Denosumab use and occurrence of AFF

A total of 31 AFFs in 22 patients were reported after the use of denosumab in 14 case reports and two clinical trials. The characteristics of these patients are summarized in **Table 5**. Ethnicity was stated only in three reports, with subjects of a Caucasian (n=1) or Japanese (n=4) background (50-52). Eleven patients with 15 AFFs were treated for osteoporosis with denosumab 60mg half-yearly (43, 52-60), while 16 AFFs in 11 patients have been reported after denosumab treatment with a high dose of 120mg monthly for metastatic bone disease (50, 51, 61-64).

AFF occurred in eight patients without prior bisphosphonate use (9, 52, 59-61, 63, 64) of which four were in patients treated in an oncology setting (61, 63, 64), meaning that only four cases were documented of AFF after use of denosumab for management of osteoporosis (9, 52, 59, 60).

Two bisphosphonate-naïve individuals developed an AFF following the sixth and the fourteenth dose of denosumab in the FREEDOM-trial, a phase III clinical trial with denosumab in 4550 women with osteoporosis (59, 60). The first patient stopped denosumab and achieved fracture healing within six months, whilst the latter continued denosumab but no data on the healing of AFF are available in this case (personal communication by Amgen).

One 60-year-old male who had been on glucocorticoids for asthma for over 30 years developed an AFF without any previous bisphosphonate use, two months after the second dose of denosumab that was given in a randomized controlled trial of denosumab in patients with glucocorticoid-induced osteoporosis (9). The fourth case without bisphosphonate-

exposure concerns an incomplete, medially located AFF after only one injection of denosumab without abnormalities on X-ray but with periosteal reaction on the MRI scan (52). Although stress fractures resembling AFF located on the medial instead of the lateral cortex have been described (65), this case does not meet the diagnostic criteria of AFF according to the ASBMR Task Force (3). The four bisphosphonate-naïve AFF cases treated for metastatic bone disease occurred after 21, 24 or 42 doses of 120 mg denosumab monthly (61, 63, 64).

In two other cases, the influence of bisphosphonates on the risk of AFF cannot be excluded, but AFF was preceded by very short bisphosphonate treatment before starting denosumab (53, 55). These two cases are very similar, since both patients had used alendronate for just a few weeks before switching to strontium ranelate because of side effects, which was subsequently replaced by denosumab, again because of intolerance to the drug. Both patients developed an AFF after three doses of denosumab (53, 55).

These reports of AFF after denosumab with minimal or no previous bisphosphonate use are suggestive of a role for denosumab in the development of AFF but the numbers are small and AFFs have also been reported rarely in patients never treated for osteoporosis (5, 66, 67). In another report, the AFF appeared to be triggered by one dose of denosumab in December 2012, after five years of alendronate use between 1994-1999 (57) followed by a subsequent drug holiday for 13 years.

Denosumab use after AFF

We found seven papers that report on the use of denosumab after an AFF in 10 patients (18, 45, 58, 68-71).

Bisphosphonates switched to denosumab treatment

Seven patients switched from bisphosphonates to denosumab just before or after the first AFF. One patient with an incomplete AFF after four years of risedronate who underwent preventive placement of an intramedullary gamma-nail, was switched to denosumab and had delayed healing after six and 12 months (68).

In a case series of complete AFFs associated with alendronate use (69), four patients started denosumab after the first AFF. There were four different outcomes. One patient had delayed fracture healing at 12 months but with minimal pain and almost the same activity level. One patient had a second complete AFF on the contralateral side one year after switching to denosumab; this contralateral AFF showed bridging callus formation at nine months' follow-up. One patient had bridging callus formation at 12 months and was pain-free. One patient had resumed normal daily activities at 18 months of follow-up and radiographs showed bone healing (69).

In a case report one patient, who sustained a first complete AFF after one dose of denosumab and eight years of alendronate (58), continued denosumab treatment but sustained a second complete AFF after three more doses of denosumab. The authors describe healing of both AFFs within five months postoperatively.

Another case is described of denosumab started postoperatively for complete AFF with full weight-bearing after three months and no adverse events at 18 months of follow-up; complete bony union was achieved at one year postoperatively (70).

Teriparatide switched to denosumab treatment

Three cases are reported of denosumab therapy following teriparatide. One case involved bilateral incomplete AFFs without visible fracture lines after seven years of oral bisphosphonates who was treated with teriparatide for 18 months and a subsequent drug holiday of 12 months (71). The cortical thickening had almost completely flattened on X-rays when denosumab was prescribed as treatment for low bone mineral density (BMD). The

authors report that the patient had increasing thigh pain in both upper legs six months after the first dose of denosumab and that X-rays and bone scintigraphy showed recurrent incomplete bilateral AFFs with presence of a lucent line after which the surgeon decided to perform bilateral internal fixation (71). Two case reports (one with incomplete AFF and one with complete AFF) mention that the initiation of denosumab therapy had a good outcome in the short term (< one year) (18, 45) .

Raloxifene

Raloxifene use and occurrence of AFF

Six papers (29, 49, 72-75) stated the use of raloxifene prior to the diagnosis of AFF in eight patients, although in four patients it was unclear whether this was preceded by bisphosphonate treatment (74, 75). Two patients had simultaneous use of raloxifene and bisphosphonates during six months and six years, respectively (49, 72). One had had prior bisphosphonate use (29). In a case series of surgically treated AFFs from Japan (73), a patient treated with raloxifene only was reported. This concerned a 77-year-old woman who had taken raloxifene and vitamin K2 for only one year when she sustained an AFF after a fall from standing height. Because delayed union was suspected, she received low-intensity pulsed ultrasonography three months postoperatively and partial fracture healing was seen nine months after the surgery (73).

Raloxifene use after AFF

We found reports of two patients treated with raloxifene after AFF, in both cases after teriparatide treatment (37, 46). One 63-year-old Asian woman received ten months of teriparatide after incomplete AFF with a visible fracture line, which was subsequently replaced by raloxifene. The fracture line had already diminished after three months of teriparatide and was invisible 15 months after the diagnosis, which was five months after

starting raloxifene (37). One 78-year-old woman with incomplete AFF with a lucent line received teriparatide; the fracture line had almost disappeared three months postoperatively. After 12 months of teriparatide, she switched to a SERM, most likely raloxifene, and had an event-free follow-up three years after the diagnosis (46).

Romosozumab

Twelve studies have been performed with romosozumab. Two studies reported three cases of AFF. One case of AFF occurred 3.5 months after the first monthly dose in a phase III clinical trial (76), but the association between romosozumab and the AFF is questionable given that the participant had complained of prodromal pain prior to the first romosozumab administration. Two cases of AFFs that occurred during open-label alendronate treatment after one year of monthly romosozumab in another trial (77).

Abaloparatide

A a total of nine clinical trials with abaloparatide were published. No cases of AFF were reported in patients who used or had used abaloparatide.

Discussion

In clinical practice there is great uncertainty of how to treat patients after they have sustained an AFF. This relates both to potential (positive or negative) effects of bone agents on the healing of the fracture and to the safety of osteoporosis drugs in those patients, who are still at high risk of fragility fracture after an AFF. Bisphosphonates are usually stopped, because patients are considered at risk of an AFF of the other femur since bilaterality is commonly reported, varying from 28% up to 44% (2, 7).

In this systematic literature review, we aimed to assess the effects of teriparatide, denosumab,

raloxifene, romosozumab and abaloparatide on both the occurrence and healing of AFF in order to give recommendations for medical management. It is difficult to draw firm conclusions, because there are no reported RCTs of treatment in AFF patients with any of these drugs.

Based on descriptions of 165 AFFs treated with teriparatide in observational studies, we made a crude estimate of effects of teriparatide on radiological healing of AFF after six and 12 months. The majority of surgically treated incomplete (n=9, 90%) and complete AFFs (n=44, 76%) healed within six months of teriparatide treatment, in contrast non-operated incomplete fractures treated with teriparatide (n=13, 43%) and complete AFFs that were not treated with teriparatide (n=34, 51%). The reported data are insufficient for an evidence-based recommendation of the use of teriparatide to accelerate healing of AFF. Yet, keeping in mind the flawed study designs and heterogeneity between studies, the observational data might suggest that teriparatide could have a beneficial effect on the healing time of surgically treated AFF, although non-union after one year can still occur. There is no evidence of improved fracture healing for conservatively managed incomplete AFFs based on these observational data. Our findings clearly show that even during and after teriparatide treatment a new AFF can occur, either as a first presentation of AFF or as a second AFF of the contralateral femur, but only in patients previously treated with bisphosphonates.

The role of teriparatide for healing of any type of fracture is debated. One meta-analysis of five RCTs in patients with osteoporotic fractures found a significantly shorter healing time in the teriparatide-treated group (78), whilst another analysis including also non-osteoporotic fractures did not demonstrate any effectiveness for teriparatide with regard to faster union (79). Two RCTs involved subjects with femoral fractures. In one trial with postmenopausal women and low-trauma femoral neck fractures, teriparatide did not improve radiological fracture healing, but the sample size was too small to detect any differences (80). The other

RCT involved premenopausal women with acute stress fractures of the lower extremities and showed a tendency towards improved healing on MRI in the teriparatide group (83.3%) in comparison to controls (57.1%), but not statistically significant (p=0.18) (81).

There are no documented cases of AFF with the use of abaloparatide. This drug might have equivalent effects on AFF as teriparatide given the biological similarity. The results from the literature search were insufficient to assess the effects on AFF healing by denosumab and raloxifene. Despite the lack of epidemiological studies, our analysis of the literature suggests that the absolute risk of AFF when using denosumab or raloxifene for osteoporosis is very low given the limited reports of AFF cases using these drugs, eleven and eight patients respectively, and they also mostly occurred after previous use of bisphosphonates. However, this risk may be increased in patients who have already had an AFF suggested by the reports of two patients with a second complete AFF (58, 69) on denosumab and in another patient with bilateral recurrent incomplete AFFs on denosumab even after use of teriparatide (71). These cases suggest curtailing use of denosumab treatment after an initial unilateral AFF. Romosozumab is linked to three AFF cases in clinical trials, but it remains to be seen if more cases of AFF will develop in patients treated with romosozumab with or without bisphosphonate exposure.

Based on our findings we conclude that there is a clear need for randomized controlled clinical trials to evaluate whether teriparatide and/or abaloparatide enhances fracture union of (any type of) AFF, since this is the only drug that is not associated with the development of AFF without prior use of bisphosphonates. The observational studies in this review are biased and lack information on confounding factors such as time between diagnosis and starting medical treatment, surgical fixation techniques, smoking, body mass index, fracture localization, use of concomitant medication and postoperative weight-bearing protocols. Currently, one clinical trial is ongoing for patients with incomplete AFF who are randomized

to receive either placebo injections or teriparatide. Changes in pain score and physical function using the WOMAC scale and the proportion of participants requiring surgery after 12 months serve as primary outcomes (82). There are no trials registered investigating teriparatide for complete AFF, non-healing AFF or electively operated incomplete AFF. Also no trials are currently evaluating the risks and benefits of antiresorptive therapy compared with placebo in AFF patients after stopping teriparatide or in AFF patients managed conservatively or surgically. It is difficult to set up an adequately powered study because of the low incidence of AFF. Therefore, an international registry of AFF cases could be very useful to gain insight into the safety and efficacy of osteoporosis drugs in relation to fracture healing, bone mineral density and bone turnover and development of new AFFs in these patients, but this is only possible when AFF patients are referred to specialized centers.

Recommendations for clinical practice based on expert opinion

Based on the results in this review and our expert opinion we advise on medical treatment for patients with AFF. Our recommendations for medical treatment are summarized in a decision tree (**Figure 2)**, encompassing the occurrence of AFF when using bisphosphonates or denosumab and what to do after a patient with AFF has completed a two-year course of teriparatide. In any case, extensive monitoring with imaging of both upper legs is advised during the first one or two years after the diagnosis of AFF, because non-healing of AFF and contralateral AFF may still occur, even on teriparatide.

When AFF is diagnosed during the use of bisphosphonates or denosumab, it is recommended to stop this treatment, since continuation may lead to worsening of the AFF or a new contralateral AFF. To prevent a rebound effect, discontinuation of denosumab could be followed by a short course of bisphosphonates or SERMs in patients with surgically treated

AFFs. In patients at low fracture risk without prevalent vertebral fractures who have only had one or two half-yearly injections, consider stopping denosumab treatment without subsequent therapy. After healing of bilateral, surgically managed AFFs, bisphosphonates or denosumab may be continued. It should be kept in mind that discontinuation after three or more years of bisphosphonate treatment may result in increased risk of hip fractures and clinical vertebral fractures as shown by some studies (83, 84), although this was not found in another recent retrospective analysis of a population-based cohort (85). Continuation of bisphosphonates might lead to a risk of atypical fractures at skeletal sites other than the femur. Anecdotally, spontaneous fractures of other long bones e.g. ulna, forearm and tibia have been reported in relation to bisphosphonate use (86-93), but no association has been established and the potential risk of such atypical fractures does not appear to weigh against the risk of typical osteoporotic fractures.

Teriparatide might be started for surgically treated AFFs, although strong evidence for improved fracture union is lacking. Further, teriparatide, SERMs, romosozumab or abaloparatide may alternatively be considered in patients at high risk of fragility fractures. SERMs are preferably prescribed in relatively young postmenopausal women who are at low risk of hip fractures and deep vein thrombosis (94). Hormone replacement therapy or tibolone might be considered when SERMs are not tolerated, preferably in younger women (< 65 years) who do not have an increased risk of venous thromboembolism, without a history of myocardial infarction or stroke and also keeping in mind the increased breast cancer risk (94). If the patient is not eligible for any of the aforementioned drugs, calcitonin can be prescribed as in accordance with the recent guideline of the Endocrine Society on pharmacological management of osteoporosis (94). The definition of high risk of fragility fractures varies across countries, but is often defined by a hip BMD T-score ≤ -2.5 SD, older age (70-75

years), a recent fragility fracture, other strong risk factors for fracture or a FRAX fracture risk score that is above country specific thresholds (95).

After two years of teriparatide, subsequent therapy may be given with raloxifene (or hormone replacement therapy) in women and – in those with bilateral surgical fixation of AFF – denosumab or bisphosphonates. In patients at the end of a (short) course of teriparatide who have low bone turnover markers after teriparatide or who are deemed to be at low risk of osteoporotic fractures teriparatide may be discontinued without further antiresorptive treatment, but close monitoring of BMD and bone turnover markers is recommended.

The considerations for each individual drug are given in more detail below.

Teriparatide

There is no evidence-based indication for teriparatide to enhance healing of AFF, but a tendency towards faster healing with teriparatide for surgically managed AFFs is seen in the limited, observational data. Hence teriparatide 20ug daily, when reimbursed, might be considered for surgically-treated AFF, both incomplete AFF and complete AFF. Even during the use of teriparatide, non-unions do still occur in surgically managed AFF. The limited data on conservatively managed incomplete forms of AFF and use of teriparatide, do not demonstrate improved fracture healing, but should be interpreted with caution, pending the result of an RCT that is awaiting results. When teriparatide is given for the sole purpose to enhance fracture healing of AFF, a short treatment duration of three to six months may suffice.

Teriparatide is a reasonable treatment option for patients who have had an AFF and are still at high risk for fragility fractures. A big clinical dilemma is what to do after a full two-year

course of teriparatide treatment. Normally, antiresorptive therapy is advised after two years of teriparatide, because the positive effects on bone mass and strength will in time disappear, as with any drug without skeletal retention. Some patients with AFF may have inherent low bone turnover, for example due to an underlying monogenetic disease (96) or due to previous long-term use of bisphosphonates. It can be speculated that accelerated bone loss after cessation of teriparatide may not occur in these cases. A few studies describe the effect of teriparatide on bone turnover in AFF patients, but the results are inconclusive. Administration of teriparatide during six months has been associated with a significant increase in bone turnover markers in patients with AFF (28, 30) and values returned almost to baseline level after two years of teriparatide (30), but pre-treatment values varied widely (30, 97) and bone turnover markers did not correlate with histomorphometric findings from bone biopsies before and after teriparatide treatment in AFF patients (97).

We suggest monitoring bone turnover markers on a regular basis in patients with AFF before, during and after teriparatide treatment and considering antiresorptive drugs when levels start to increase or when BMD starts to decrease in patients at high risk of fractures. In this situation, we suggest either a SERM, romosozumab, calcitonin, tibolone, estrogens, denosumab or bisphosphonates, based on sex and on bilaterality of surgical intervention (see below).

Denosumab

When a patient sustains an AFF during the use of denosumab, the risk of a rebound effect with rapid loss of BMD and potential risk of multiple vertebral fractures following cessation of denosumab (98) must be weighed against the potentially increased risk of a contralateral AFF when continuing denosumab. Patients who have already had vertebral fractures appear to be at greatest risk of developing multiple vertebral fractures after denosumab discontinuation. In general, a course of bisphosphonates is recommended after stopping denosumab (98). This

is not advisable for a conservatively managed incomplete AFF, but a short course of a SERM or bisphosphonates may be considered in patients with bilateral surgically treated AFFs or a unilateral surgically treated AFF without any radiological signs of incomplete AFF of the contralateral femur. Denosumab could be stopped without follow-up therapy in patients at low risk of fragility fractures without prevalent vertebral fractures, especially in those who have only had one or two half-yearly injections of 60 mg subcutaneously.

For patients at high risk of fragility fractures, a switch to teriparatide or a SERM could be considered. However, the rebound effect after stopping denosumab might still occur since teriparatide increases bone turnover. One should also be aware of a decrease in BMD especially at cortical sites, as was seen in osteoporotic women who transitioned to teriparatide after two years of denosumab in the DATA-switch study (99). Alternatively, hormone replacement therapy or tibolone can be considered in women in absence of contra-indications such as a high risk of breast cancer of deep veen thrombosis, history of stroke or myocardial infarction. Calcitonin is an option if the patient does not tolerate any of the aforementioned drugs (94).

Denosumab could be continued or initiated when the patient has bilateral surgically treated AFFs and a persistently high risk of fragility fractures, including those who have completed two years of teriparatide. Denosumab therapy for up to 10 years has been associated with increasing BMD and low fracture incidence (59). Long-term use of denosumab could especially be considered in elderly patients with a life expectancy of less than 10 years, for whom this may serve as life-long osteoporosis treatment.

Raloxifene

Raloxifene could be considered as follow-up therapy after teriparatide when bone turnover markers are high in postmenopausal women who do not have a history of venous thrombo-embolic events. Preferably it is given to women who are relatively young and are at lower risk

of hip fractures. As mentioned above, it could also be considered in patients who have to stop denosumab because they are at risk of another AFF and to potentially prevent the rebound in bone turnover and risk of multiple vertebral fractures, especially when they have already had vertebral fractures. However, no studies have been performed using SERMs to prevent rebound after stopping denosumab. Because it has a weaker antiresorptive effect than bisphosphonates or denosumab and few cases of AFF have been reported on raloxifene, this may be a preferred option after teriparatide (100, 101). Yet it should be kept in mind that raloxifene is not regularly prescribed for osteoporosis, hence a low number of AFF associated with raloxifene does not guarantee a lower risk of AFF compared to other antiresorptive drugs.

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Legends

Figure 1. The results for each type of drug were categorized according to study design and fracture type.

Figure 2. Decision tree with considerations for medical management after AFF.
^ Definition may vary across countries, e.g. a hip BMD T-score ≤ -2.5 SD, older age (70-75 years), a recent fragility fracture, other strong risk factors for fracture or a FRAX fracture risk score that is above country specific thresholds (95).
Raloxifene or bazedoxifene are preferably prescribed in relatively young postmenopausal women who are at low risk of hip fractures and deep vein thrombosis (94), or in women in whom the use of teriparatide is contra-indicated.
[#]In case of intolerance to SERMs, hormone replacement therapy or tibolone could be considered in women with a low risk of deep vein thrombosis and breast cancer, without a history of myocardial infarction or stroke (94).
+ Switching denosumab to teriparatide may result in progressive BMD loss.
0 Be aware that antiresorptive therapy may be needed after stopping denosumab.
[A] Calcitonin can be prescribed in patients who are not eligible for bisphosphonates, SERMs, hormone replacement therapy, tibolone, abaloparatide or teriparatide.

Table 1. Demographic characteristics of case reports on teriparatide use in AFF patients.

NS = not stated, F = female, M = male
[1] From case series, only patients in whom the effect of teriparatide could be assessed on healing or occurrence of AFFs were included in this table.
[2]The number of AFFs included (contralateral) AFFs that had already healed by the time teriparatide was started. This means that the total number of AFFs in this table is higher than the total number of AFFs that was treated with teriparatide.
[3] The country of the affiliation is given, when ethnicity of the AFF case was not specified in the article.
[4] The types of bisphosphonates prior to the occurrence of the first AFF. When a patient had used several antiresorptive drugs, the total number of years the patient had used this specific drug is indicated in brackets. In some cases, type of bisphosphonates was unknown ("bisphosphonates"). For intravenous bisphosphonates the dosage and treatment interval are given in the table. Alendronate dosages included 70mg weekly or 10mg daily. Etidronate was given 400mg two-weekly, ibandronate 150mg monthly, risedronate 35mg weekly and raloxifene 60mg daily.
[5] The total duration of antiresorptive drugs use prior to the first diagnosis of AFF is given in years, not including drug holidays.
[6] No access to full-text article.

Table 2. Summary of retrospective cohorts of AFF patients and use of teriparatide.

TPT = teriparatide, AR = antiresorptive, NS = not stated.
Percentage of women, mean age, antiresorptive use and mean duration of antiresorptive treatment were based on the whole cohort, including controls.
**When the number of AFFs is not stated in the article, the number of patients is given.*

Table 3. Summary of prospective studies on AFF patients and use of teriparatide.

TPT = teriparatide, AR = antiresorptive, NS = not stated
Percentage of women, mean age, antiresorptive use and mean duration of antiresorptive treatment were based on the whole cohort, including controls.
** The number of patients is given.*

Table 4. Radiological healing of AFF after teriparatide: pooled data.
NA = not applicable, TPT = teriparatide
Five AFFs that underwent surgical procedures from Takakubo et al. were categorized as complete fractures. In the study by Miyakoshi et al., one non-operated incomplete AFF and one surgically treated incomplete AFF on teriparatide and eight complete AFFs without teriparatide were labeled as healed by the authors between six and 24 months. These fractures were categorized as "healing at 12 months". From the study by Sato et al., only progression to complete AFF in one patient on teriparatide and one without teriparatide could be established, whilst for the other 19 incomplete AFFs the fracture healing was not specified.

Included articles:(10, 13, 15-17, 20-26, 29-38, 40-49)

Excluded: Patients (n=7) without fracture consolidation after ≤ six months of teriparatide use (18, 50, 51) (n=3), (20) (n=3 with surgery after three months), (48) (n=1, case no. 3), fracture healing could not be assessed with certainty (52, 53), duration of fracture healing or fracture type were not reported (14, 19, 27, 28).

Table 5. Occurrence of AFF during or after the use of denosumab.

BP = bisphosphonate. Parameters are based on the time of the first AFF. Mean duration of bisphosphonates was calculated in bisphosphonate-users only. Incomplete fractures with progression to complete fractures were excluded from the number of incomplete AFFs. Denosumab was dosed 120mg monthly in oncological patients and 60mg six-monthly in osteoporosis patients. Missing data: age (n=2)(63), mean duration of bisphosphonates (n=3) (55), median no. of denosumab doses (n=3) (55). Included articles: (8, 42, 54-68)

Figure 1.

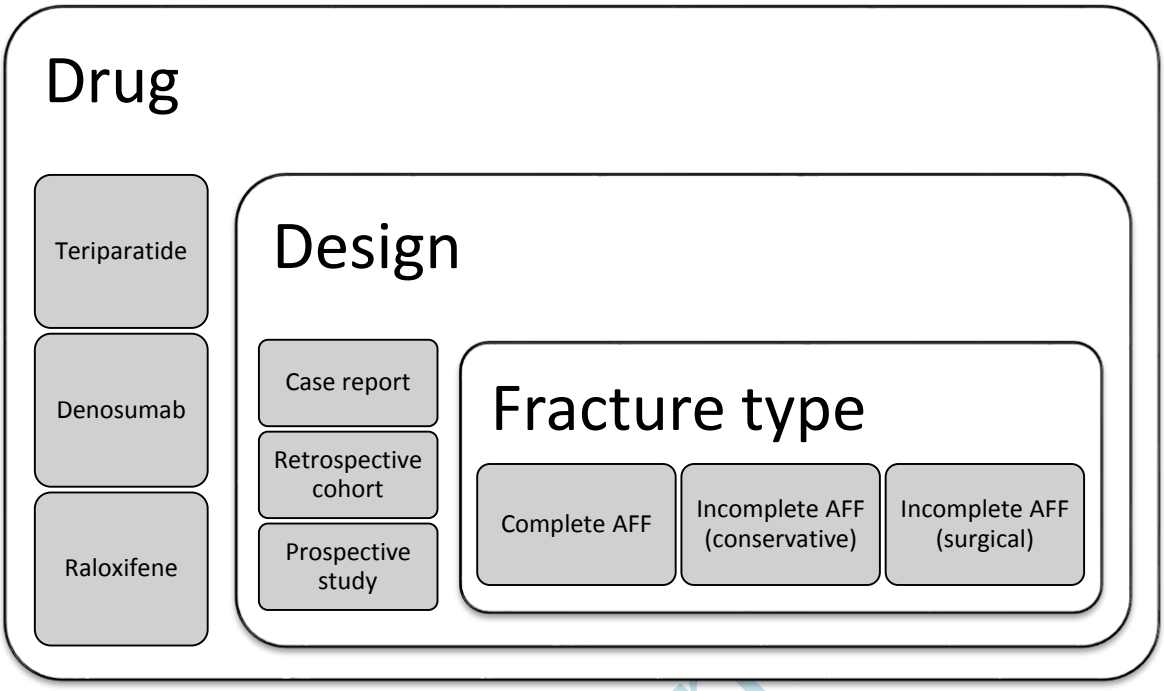
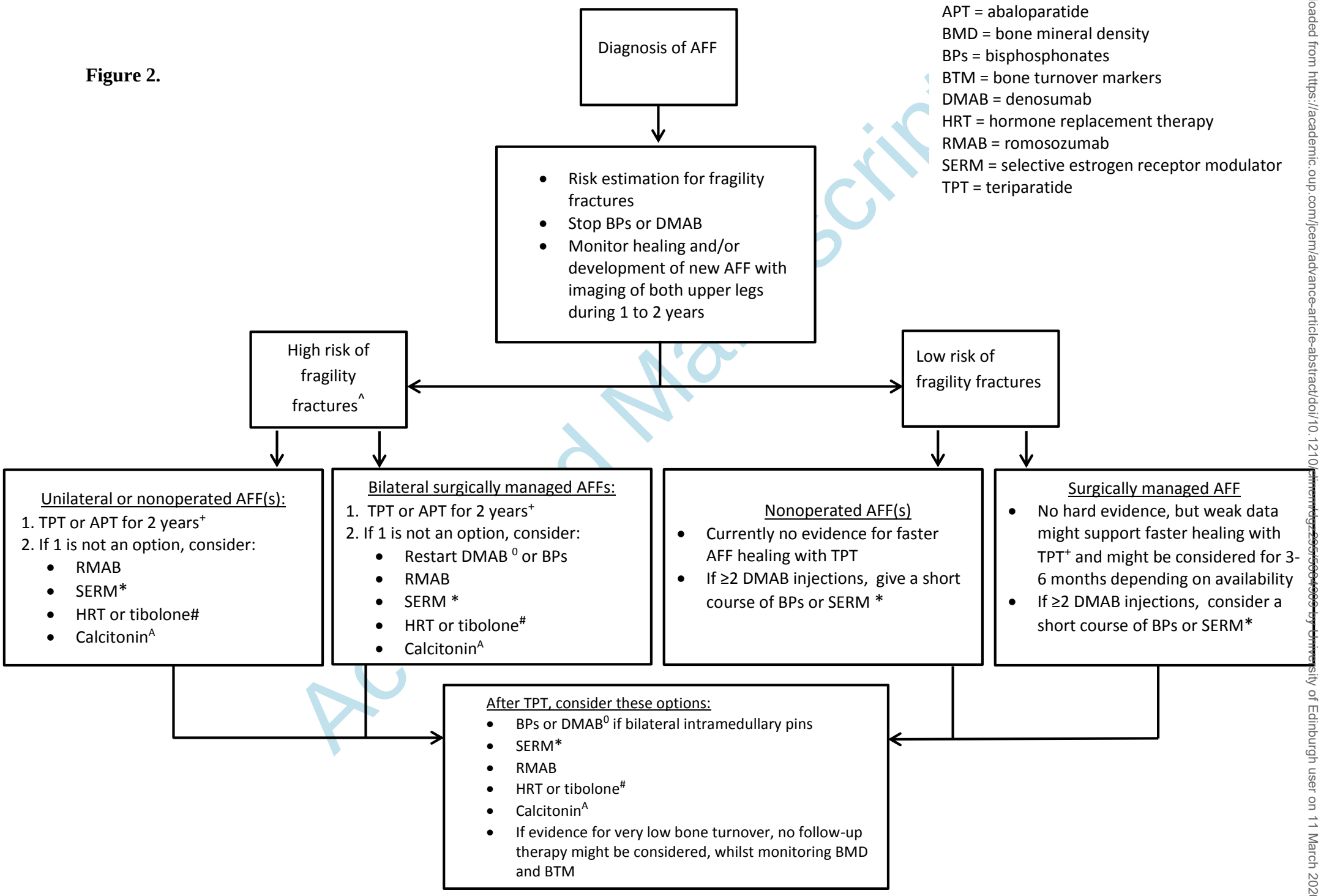


Figure 2.



APT = abaloparatide
BMD = bone mineral density
BPs = bisphosphonates
BTM = bone turnover markers
DMAB = denosumab
HRT = hormone replacement therapy
RMAB = romosozumab
SERM = selective estrogen receptor modulator
TPT = teriparatide

Table 1.

Reference	n = patients[1]	n= in-complete AFF[2]	fracture line visible	n= complete AFF[2]	Sex	Mean age	Background[3]	Antiresorptives[4]	Condition	Mean duration treatment in years (range)[5]
Al Azzani, 2015	1	1	yes	0	M	54	Caucasian	alendronate (5), ibandronate (5)	cystic fibrosis	10
Carvalho, 2011	1	0	-	1	F	77	Caucasian	alendronate	postmenopausal osteoporosis	4
Cerveró, 2015	1	1	yes	1	F	71	(Spain)	alendronate	postmenopausal osteoporosis	5
Chiu, 2013	1	2	yes	0	F	63	(Taiwan)	alendronate	postmenopausal osteoporosis	7
Chew, 2013	1	1	yes	0	F	70	(Malaysia)	alendronate	back pain	6
Etxebarria-Foronda, 2015	1	0	-	1	M	21	(Spain)	pamidronate iv (3), alendronate (5)	osteogenesis imperfecta	8
Fukuda, 2014	1	1	yes	1	F	74	(Japan)	alendronate	postmenopausal osteoporosis	6
Giannotti, 2013	1	1	no	1	F	65	Caucasian	"bisphosphonates"	NS	6
Gomberg, 2011	1	2	no (2)	0	F	63	Caucasian	alendronate	glucocorticoid-induced osteoporosis	13
Holm, 2014[6]	1	0	-	1	NS	NS	(Norway)	"bisphosphonates"	osteogenesis imperfecta	9
Huang, 2012	1	1	yes	0	F	63	Asian	alendronate	vertebral fractures	3
Iwata, 2014	1	0	-	2	F	56	Asian	incadronic iv 10mg two-weekly (3), pamidronate iv 90 mg monthly (1), zoledronate iv 4mg monthly (5)	metastatic bone disease	9
Jain, 2011	1	1	NS	1	F	75	(India)	alendronate	osteopenia	6
Kaur, 2016	1	1	no	0	F	70	Guyanese	alendronate	postmenopausal osteoporosis	10
Lampropoulou-Adamidou, 2013	1	0	-	1	F	84	Caucasian	alendronate (12), ibandronate (1)	postmenopausal osteoporosis	13
Mastaglia, 2016	1	1	no	1	F	57	Caucasian	alendronate	osteopenia	7
Nguyen, 2017	1	0	-	1	F	65	(Australia)	alendronate	postmenopausal osteoporosis	11

Ramchand, 2016	1	2	no (2)	0	F	82	(Australia)	alendronate (6), risedronate (1)	rib fracture osteoporosis	7
Reddy, 2012	1	0	-	1	M	70	Asian	zoledronate iv 4mg monthly	androgen deprivation therapy	2
Righetti, 2018	1	2	yes (1)	0	F	67	Armenian	alendronate	hypophosphatasia	10
Román, 2015	1	0	-	2	M	72	(Spain)	alendronate	glucocorticoid-induced osteoporosis	11
Schilcher, 2015	1	0	-	1	F	84	(Sweden)	"bisphosphonates"	rheumatoid arthritis/Wegener granulomatosis	16
Selga, 2016	1	0	-	2	F	62	(Spain)	alendronate (10), risedronate (2), ibandronate (3), denosumab (2)	osteoporosis	17
Spyridonidis, 2014	1	1	yes	1	F	78	(Greece)	alendronate	osteoporosis	8
Stathopoulos, 2011	1	0	-	1	F	76	Caucasian	zoledronate iv 4mg yearly	osteoporosis	6
Tan, 2017	1	1	yes	0	M	63	(Singapore)	alendronate (7), etidronate (2)	osteogenesis imperfecta	9
Tarazona-Santabalbina, 2013	1	1	yes	1	F	73	(Spain)	alendronate	osteoporosis	13
Tsuchie, 2015	2	3	yes (3)	0	F	78	(Japan)	alendronate	osteoporosis	5 (4-6)
Uppin, 2016	1	0	-	2	F	56	(India)	alendronate	rheumatoid arthritis	4
Vaishya, 2013	1	2	yes (2)	0	F	63	(India)	alendronate	osteoporosis	3
Visekruna, 2008	2	0	-	3	F	69	Caucasian	alendronate, raloxifene	steroid-dependent rheumatoid arthritis	13 (10-16)

Table 2.

Reference	Total cohort, *n*	Patients on TPT, *n*	Controls without TPT, *n*	Fracture type of TPT users*	Female, *n* (%)	Mean age (years)	Country	AR use	Mean duration AR, years (range)	Main outcome
Cheung, 2013	22	22	0	Incomplete *surgical = 3 conservative = 19*	22 (100%)	66	Canada	Yes (100%)	12 (3.4-28.7)	Of 19 incomplete AFFs without surgery, 2 healed, 5 were healing, 12 were stable after 2 years of TPT, but 4 patients developed new incomplete AFFs
Lee, 2013	51	19	32	Incomplete *surgical = 12 conservative = 7*	50 (98%)	70.4	South Korea	Yes (77%)	4.5	7 patients on TPT and 19 patients without TPT required surgery; Use of teriparatide did not significantly reduce the need for surgery (p = 0.210)
Lee, 2017	44	14	30	Complete *n = 14 AFFs*	44 (100%)	70.1	South Korea	Yes (100%)	5.1	Time to healing was 4.9 months in TPT-group,6.6 months in non-TPT-group and 7.1 months in those continued on bisphosphonates
Miyakoshi, 2015	34	NS (21 AFFs)	NS (24 AFFs)	Incomplete *surgical = 5 AFFs conservative = 5* Complete *n=11 AFFs*	34 (100%)	78.5	Japan	Alendronate or risedronate (100%)	4.4 (1-11.7)	Time to healing was significantly shorter for all surgically treated AFF in TPT-group (5.4 vs. 8.6 months)
Petraszko, 2016	7	6	1	Incomplete *conservative = 8 AFFs surgical = 1 AFF*	7 (100%)	70.7	USA	Yes (100%)	10.6 (7-15)	Fracture line disappeared in 2 of 6 AFFs with a visible line within one year of TPT

Saleh, 2012	10	9	1	Incomplete *conservative = 13 AFFs*	10 (100%)	66.8	USA	Alendronate or risedronate (100%)	10 (4-17)	5 AFFs without line all healed, 7 of 8 AFFs with fracture line had surgery after 3 months of TPT
Sato, 2017	12	6	6	Incomplete *conservative = 6*	12 (100%)	55.6	Japan	Alendronate (100%)	5.9 (3.1-9.3)	All AFFs on continued bisphosphonates deteriorated; 1 AFF progressed to complete fracture after 8 months of TPT
Takakubo, 2017	8	4	4	NS *surgical = 5 AFFs*	8 (100%)	54.9	Japan	Alendronate, risedronate, minodronate (100%)	4.3 (2-10)	Time to healing was 11.5 months in 5 AFFs on TPT and 13.3 months in 6 AFFs without TPT, but 1 AFF was not healed after 1 year and lost to followup in the TPT-group
Yeh, 2017	13	NS (8 AFFs)	NS (8 AFFs)	Complete *n = 8 AFFs*	13 (100%)	70.2	Taiwan	Alendronate (100%)	4.0 (2.5-6)	Time to healing was 4.4 months in the TPT-group versus 6.2 months in the non-TPT group

Table 3.

Reference	Total cohort, *n*	Patients on TPT, *n*	Controls without TPT, *n*	Fracture type of TPT users*	Female, *n* (%)	Mean age, (years)	Country	AR use	Mean duration AR, years (range)	Main outcome
Chiang, 2013	14	5	9	Incomplete *n = 4* Complete *n = 1*	13 (93%)	76	Australia	Alendronate, risedronate, pamidronate, zoledronate (100%)	7 (4-10)	TPT users: 2 healed, 3 had partial healing Controls: 3 prophylactic surgery, 1 contralateral AFF, 6 with non-union
Greenspan, 2018	13	13 - 7 immediate post-surgery - 6 on teriparatide 6 months postoperatively	0	Incomplete *surgical = 1* Complete *n = 12*	13 (100%)	74	USA	Risedronate, ibandronate, alendronate (100%)	NS	Higher bone healing scores in immediate TPT group, but not statistically significant
Watts, 2017	14	14	0	Complete *n = 9* Incomplete *surgical = 1 conservative = 4*	14 (100%)	68	USA	Alendronate, ibandronate, zoledronate, risedronate (100%)	8.8 (3-14.5)	Complete AFFs: 4 healed, 5 partial healing, 1 nonunion. Incomplete AFF: 4 partial healing, 3 unchanged. 2 contralateral complete AFFs

Table 4.

Fracture healing and teriparatide use *n*=140 patients	Incomplete AFF (conservative)	Incomplete AFF (surgical)	Complete AFF	
	TPT	TPT	TPT	*No TPT*
Number of AFFs (total 165)	*30*	*10*	*58*	*67*
Healing ≤ 6 months of TPT	13 (43%)	9 (90%)	44 (76%)	*34 (51%)*
Healing 6 < or ≥ 12 months of TPT	4 (13%)	1 (10%)	9 (16%)	*29 (43%)*
No union achieved at 12 months	9 (30%)	-	5 (9%)	*4 (6%)*
Progression to complete AFF	4 (13%)	NA	NA	*NA*

Table 5.

	Osteoporosis (*n*=11)	Bone metastases (*n*=11)	Overall (*n*=22)
No. of AFFs	15	16	31
Mean age (min-max)	70.7 (59-81)	54.7 (50-86)	62.7 (50-86)
Female (%)	10 (91%)	10 (91%)	20 (91%)
Complete AFFs (%)	11 (73%)	6 (38%)	17 (77%)
Incomplete AFFs (%)	4 (27%)	10 (62%)	14 (64%)
BP use	7 (64%)	7 (64%)	14 (64%)
BP-naive	4 (36%)	4 (36%)	8 (36%)
Mean duration of BP, years (range)	9.0 (5 weeks-15 years)	7.8 (6-11.3)	8.4 (5 weeks – 15 years)
Number of denosumab doses, mean (range)	3.2 of 60mg half-yearly (1-14)	30 of 120mg monthly (18-48)	-
Accumulative dose, mg/year	120	1440	-
Number of denosumab doses in BP-naïve patients, mean (range)	5.8 (1-14)	29 (21-42)	-